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ORIGINAL PAPER

From the analysis of European accident data to safety assessment for planning: the role of good vehicles in urban area

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Abstract
Purpose Within the field of goods vehicles mobility, the paper points out the road safety that has impacts on both social and economic sustainability spheres. The contribution of goods vehicles is investigated and the results obtained for the larger European countries are discussed.
Methods The used methodology is statistic-descriptive, extracting from a large available database successive and more in-depth information. Starting from aggregated (at national level) data for accidents involving goods vehicles in urban area, the paper evidences the urban junctions as the main critical situation for accidents.
Results One of the main findings is that urban goods vehicle accidents received little attention, but being an important segment of urban mobility, much remains to do for reaching the zero-accident EU goal by 2050 in this segment.
Conclusions The paper, in the context of European urban planning, finalises the analysis results, reviewing the main methods to assess road accidents, and linking mobility simulation and safety simulation models. The findings of this study can represent the base for developing successful city plan. In fact, paper provides some indications to researchers and city planners for identifying which are the main factors to be investigated and monitored for improving urban road safety.

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Keywords Road accidents · Goods vehicles safety · Urban junction · Pedestrian safety · Safety models · Safety plan · SUMP

1 Introduction

The importance of urban goods transport is related to increase in urban populations and continued economic growth in urban areas (Browne et al. [1]). Furthermore, the freight transportation contributes to congestion, air pollution, noise and to raise logistic costs, and hence the price of products. Besides, about the 69% of EU road accidents occur in cities (White Paper [2]).

In relation to the sustainability, the costs due to road accidents can be referred to the accident victim (*social*) and to the road accident (*economic*). The former ones refer to human costs, such as cost of human life (lost productivity, non-pecuniary damage - moral and biological) and health care costs (costs of medical treatment). The latter ones are general costs due to the accident, such as property damage (damage to vehicles, buildings, roads and so on) or administrative costs (costs of intervention of the emergency services, litigation costs and administration).

In this context, the local administrators are looking at city logistics measures to limit these types of urban freight impacts (Russo and Comi [3]; Lindhom and Behrends [4]; Danielis et al. [5]; Ville et al. [6]), and models for ex-ante plan safety assessment have to be used.

In a general urban planning process, the analysis, presented below, can provide some indications to researchers and planners for identifying which are the main factors to be investigated and monitored to reach the zero-accident goal given as a focal target by the EU within 2050. The paper evolves analysing subsequent stages from the safety at urban level to

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the localization of accidents, skipping in-depth disaggregated statistical analysis and using simple statistical formulation to focus on the main factors to be obtained from the European national dataset.

Although, urban areas represent the areas with highest percentages of accidents (Section 2), their contribution has not been investigated and a safety policy for urban roads as made for highways and motorways (with very important and performing outcomes) is missing. Then, a first objective of the paper is to extract from the European big data, often unreadable, the main evidences for road accidents in urban areas, focusing on the different decreasing trends realized in the larger European countries.

Goods vehicle contribution to accident is high because of consequences occurring when they are involved (Section 3) in relation to the differential dimension with car and pedestrian. Following this physical notation, a second macro objective is to stress the contribution of goods vehicles to road accidents in European urban areas: first resuming the weight on accidents, deaths and injuries and subsequently the weight for each country, conditioned to the total vehicle*kilometres travel in urban areas.

Leaving from urban general results, a successive analysis could give a benchmark for identifying potential places of accident (Section 4). The third objective is to investigate and obtain the reference situations for the accidents involving urban goods vehicles. The urban junctions result the most critical situations for accidents. A specific focus is also developed for the road accidents involving urban goods vehicles and pedestrians for the high visibility impact in the natural commercial city centre.

Into a sustainable urban mobility plan, specific parts on road safety must be developed (SUMP [7]) including a general urban safety assessment procedure (Section 5) that allows safety indicators describing the status of transport and mobility in the city, in relation to single link and single junction, to be identified. The paper has also the objective to define a procedure for computing indicator values. The procedure has to start ex ante from the results (i.e. in terms of vehicle flows) obtained by passenger/freight urban mobility simulation models. Subsequently, the main elements of potential accidents can be recognized by applying analysis and safety simulation models.

Some conclusions and operative indications to meet the future safety goals, for good vehicles in urban areas, are given in Section 6.

2 The road safety in European urban areas

Road traffic accidents in the Member States of the European Union annually claim about 43,000 lives and leave more than 1.8 million people injured, representing estimated costs of 160 billion euros (ERSO [8]). About 36% of deaths in the EU-19 occurred within urban areas. As revealed by national European surveys, the main actions have been addressed to improve road safety at extra urban level driven to the consequences that are usually more dangerous than those in urban environment are. Therefore, below, first the urban road safety in all Europe is discussed, subsequently a zoom on the larger European countries is provided.

2.1 The road safety in Europe at urban level

Referring to road safety, in urban areas there is a combination of different types of vehicles on the road that increases the risk of accidents. In the EU-19, the total number of fatalities within urban areas each year has fallen, while the proportion on total has increased slightly (DaCoTA [9]; Nghiem et al. [10]). By 2050, the EU should move close to zero fatalities in road transport. In line with this goal, the EU aims at halving road fatalities by 2020 (White Paper [2]). Unfortunately, in 2014, the results show about 1% fewer deaths than reported in 2013. In order to halve the number of road deaths by 2020, the road fatality numbers must go down at a higher speed from today and onwards (EU [11]). Unfortunately, as shown along the paper, goods vehicle contribution has not satisfactory pointed out.

At European level, in the 2009, the goods vehicles caused the 4% of fatalities in urban areas and the 60% of it was due to lorries (under 3.5 tons; DaCoTA [12]). It should be noted that goods vehicle flows are driven by end-consumer demand. As revealed by some surveys carried out in the larger European cities (Schoemaker et al. [13]; Gonzalez-Feliu et al. [14]), the 69% of urban distances (veh * km) covered each day by motorized vehicles consist of shopping trips, 24% of restocking trips (e.g. deliveries to shops, hotel, restaurant or catering activities) and the remaining 7% result from urban management (e.g. building sites, waste collection, network maintenance). Besides, shopping is the second most frequent type of urban travel for passenger. The average distance travelled per inhabitant is less than 2 km, against 0.8 km due to deliveries and urban management flows. Trucks tend to produce serious consequences when involved in collisions with passenger cars or pedestrians. A number of studies has examined truck involvement in road accidents (Lemp et al. [15]; Gitelman et al. [16]), although only few of them have focussed upon accidents in urban areas. As discussed in the following, although the level of detail of the main European safety statistics (e.g. CARE database) is insufficient to provide a fully accurate view (Tavasszy and de Jong [17]; Yannis et al. [18]), some analyses can be performed and subsequent indications can be drawn.

2.2 The urban accident trends in the larger European countries

In the following, the analysis is detailed for the larger European countries for which data on road accidents were available according to CARE database (i.e. European centralised database on road accidents, which result in death or injury across the EU): France, Germany, Italy, Spain and United Kingdom. The available data cover the time between the 1995 and 2010. Although, CARE database could present some limits due to the different standards used in the past for collecting road accident data, it remains the main available and complete dataset for these types of analyses. For each country, the data are stored according to some key-criteria: area type (i.e. urban and non-urban), junction (i.e. junction, non-junction, no-defined), motorway (i.e. motorway, no-motor way, no-defined), transport mode (i.e. agricultural tractor, bus or coach, car and taxi, heavy and light goods vehicle, moped, motor cycle, pedal cycle, pedestrian, other), vehicle age, number of pedestrians, number of persons, number of vehicles, accidents, killed at 30 days and injured people.

As confirmed by the literature (WHO [19]; White Paper [2]), some major countries in Europe have managed to reduce their number of road accidents in the last years, but for some of them (e.g. France and Spain) the downward trends in road traffic accidents have started to flatten, suggesting that extra steps are needed to reduce these rates further. Using regression methods for analysing road safety, Table 1 reports the trend factors of the *total yearly national road accidents* (N_{na}) in the five countries. The value of adjusted R-square good-of-fit statistic (R^2_{adjusted}) was computed as (Washington et al., [20]):

$$R^2_{\text{adjusted}} = 1 - \frac{SSE/n-p}{SST/n-1} = 1 - \frac{n-1}{n-p} \cdot \frac{SSE}{SST},$$

where

- *SSE* is the sum of square errors;
- *SST* is the total sum of squares;
- *n* and *p* are the number of available observations and the number of parameters used to estimate the fitted regression line.

From data, it emerges the high average slope of Germany, Italy, United Kingdom and France with respect to Spain, for which the average modelled slope of number of deaths is positive. Specific variables defined by the ratio between the number of accidents and the population, or the total national vehicular pax*km can be also developed to point out this phenomenon.

In particular, although the number of accidents has fallen, those within urban areas are more than 60% for the larger European countries and it is remained quite constant along the last decades (*yearly percentage of urban road accidents* - P_{nua}; Table 2). For example, the last Italian official statistics confirm that, in 2012, the percentage of urban accidents is quite constant and equal to 75% (Istat [21]) and shows that local administrators have to point out the problems and to promote different and further actions in order to improve the sustainability and liveability of cities. In addition, according to the results summarised in Tables 1 and 2, there are countries (e.g. Germany) that are reducing the total number of road accidents but their urban percentages are increasing, and countries (e.g. Italy) that have high and/or increasing percentages of urban accidents.

Focusing on the percentage of killed (at 30 days) and injured people in urban areas, the analysis shows that the *yearly percentage of deaths* (i.e. ratio between number of deaths occurred inside urban area and total number of deaths at national level - P_{nud}) is quite constant along the decades (i.e. low values of estimated slope) and varies from 19% of Spain to 43% of Italy (Table 2). On the other hand, the *yearly percentage of injuries* (i.e. ratio between number of injuries occurred inside urban area and total number of injuries at national level - P_{nui}) is higher than 60% with positive trends and only for Spain it has negative slope (even if very limited) and is less than 50% (Table 2). More in-depth, these results show that, for all investigated European countries, the percentages of urban road accidents, deaths and injuries represent significant portions of national values and more attention should be paid if the safety goals have to be reached by 2050. Then, the existing EU safety problems have to be also stressed analysing the different flows components, for example as detailed below for the goods vehicles.

3 The contribution of goods vehicles to road accidents in European urban areas

3.1 The absolute national weight

According to the limitations of the main European safety statistics (e.g. CARE database [22]), in the following, some analyses based on number of accidents, number of deaths and injuries are provided focusing on urban areas.

Zooming on data available after the 2000 in Italy, Germany and United Kingdom, the *percentage of accidents involving goods vehicles in urban areas* (P_{nuag}) is quite constant among the three countries and is higher in United Kingdom (6.7%; Table 3). The *percentage of deaths* (P_{nudg}) and *injuries* (P_{nuig}) with respect to the number of accidents involving goods vehicles is lower in United Kingdom, while is averagely higher in Germany and Italy (Table 3). The comparison of these results with previous ones, in the recent years, shows that the many actions proposed by National and European Governments have allowed the total number of fatalities in road accidents to be reduced, but percentages of fatalities due to goods vehicles remained quite constant. Therefore, specific actions need because the accidents of goods vehicles often have serious consequences on human life and goods damage.

Table 1 Factors of the total yearly national road accidents (from 1995 to 2010)

	Population**	Accident			Death			Injury		
		Number of accidents N_{na}	Average modelled slope	$R^2_{adjusted}$	Number of deaths N_{nd}	Average modelled slope	$R^2_{adjusted}$	Number of injuries N_{ni}	Average modelled slope	$R^2_{adjusted}$
Germany*	81,802,257	611,451	-15,163 (−13.4)	0.95	8283	-156 (−17.9)	0.97	440,234	-12,129 (−14.9)	0.96
France	64,658,856	178,594	-8390 (−15.0)	0.94	4727	-153 (−7.2)	0.79	132,397	-7046 (−15.8)	0.95
Italy*	59,190,143	417,891	-10,292 (−17.4)	0.97	4305	-32 (−2.5)	0.74	338,713	-8583 (−13.4)	0.96
United Kingdom	62,510,197	317,984	-9171 (−11.7)	0.91	2552	-52 (−6.7)	0.76	291,749	-8313 (−9.8)	0.87
Spain	46,486,619	163,174	-189 (−0.3)	0.68	6057	102 (5.2)	0.75	137,252	-101 (−0.2)	0.65

*(−) t-st value; * after 2000; ** at 2010*

Zooming the trends of *yearly number of deaths* (N_{nudg}) and *injuries* (N_{nuig}) in road accidents within urban areas involving goods vehicles, in the last three years (i.e. 2007–2010), it emerges that: in Italy, the average slope of yearly number of deaths is 2.8, in Germany it is quite constant, while in United Kingdom it is negative and equal to 1.6. It shows that, in particular in Italy, further actions should be implemented in order to meet the 2050 goal of safety. Besides, the lines representing Italy and United Kingdom have an higher slope (the sixth column of Table 4; *death - average modelled slope*), while Germany's line is quite flat as justified that, with respect to Italy, the number of deaths in 2000 are half of Italy. Besides, although in the first investigated period (2000–2003) the number of injuries in the three countries is quite similar, the United Kingdom's trend has a slope about twice of Italy and Germany (Table 4).

3.2 The relative national weight

In order to compare and rank different traffic safety problems, the key information is the exposure. According to OECD [23], the exposure can be described in different ways, for example, involved units, distance travelled, time spent in traffic, number of trips or traffic situations related to different accident types (i.e. vehicle mileage, user mileage). These variables are not usually collected for safety purposes but for road and transport (economic) planning assessments. Referring to urban freight transport and, in particular, to the contribution of goods vehicle, the presented analysis was performed in order to investigate the relation between road accidents (in terms of number of accidents, deaths and injuries) and the dimension of goods vehicle flows measured in terms of yearly tons moved and yearly vehicle*kilometres (K_{nug}). Then, the number of accidents (including deaths and injuries occurred) per thousands of tons and (million) vehicle*kilometres performed by goods vehicles were estimated. The single accident rate was calculated for each years and each country for the years 2002–2010.

The Fig. 1 reports the *national rate of yearly urban accidents* ($NK_{nuag} = N_{nuag} / K_{nug}$) *involving goods vehicles* occurred per million of vehicle*kilometres performed by goods vehicles in urban areas. The different trends of Italy and United Kingdom with respect to Germany can be pointed out. Although Germany had the higher values of road accidents (N_{nuag}) involving goods vehicles in urban area, Germany reduced, in the investigated period, the number of accidents (NK_{nuag}) and the yearly vehicle-kilometres of about 15%. Besides, the United Kingdom, with the lower number of accidents (N_{nuag}) in 2002, presents a high negative yearly slope until 2007 determined by a reduction of N_{nuag} (about 27%) with a growth of K_{nug} (about 22%). In the following year (i.e. from

Table 2 Factors of yearly national percentages of urban road accidents, deaths and injuries (from 1995 to 2010)

	Accident			Death			Injury		
	Average yearly percentage P_{nua}	Average modelled slope	$R^2_{adjusted}$	Average yearly percentage P_{nud}	Average modelled slope	$R^2_{adjusted}$	Average yearly percentages P_{nui}	Average modelled slope	$R^2_{adjusted}$
Germany	69%	0.5% (8.8)	0.90	30%	0.5% (6.8)	0.84	63%	0.6% (9.2)	0.90
France	70%	0.1% (2.4)	0.89	29%	-0.2% (−1.9)	0.79	64%	0.8% (3.7)	0.88
Italy	78%	0.2% (3.6)	0.78	43%	0.3% (2.1)	0.84	72%	0.2% (2.8)	0.95
United Kingdom	75%	0.0% (−0.5)	0.71	40%	0.0% (−0.6)	0.72	69%	0.0% (1.9)	0.76
Spain	58%	−0.2% (−3.1)	0.84	19%	0.1% (1.1)	0.75	49%	-0.1% (−1.1)	0.75

(−) t-st value

Table 3 Percentages of the accidents, deaths and injuries involving goods vehicles in urban areas (from 2000 to 2010)

	Accident			Death			Injury		
	Average yearly percentage P_{nuag}	Average modelled slope	$R^2_{adjusted}$	Average yearly percentage P_{nudg}	Average modelled slope	$R^2_{adjusted}$	Average yearly percentage P_{nuig}	Average modelled slope	$R^2_{adjusted}$
Germany	5.0%	-0.02% (−1.5)	0.79	1.6%	0.04% (1.9)	0.84	20.4%	-0.01% (−1.3)	0.82
Italy	5.0%	-0.02% (−1.4)	0.78	1.7%	0.01% (2.5)	0.91	26.4%	0.17% (1.6)	0.81
United Kingdom	6.7%	-0.05% (−2.7)	0.95	1.1%	-0.07% (−2.9)	0.94	26.4%	-0.43% (−8.0)	0.88

(−) t-st value

2008 to 2010), there was a reduction of accidents, but an increasing of above index (i.e. about 15%). On the other hand, a total reduction of accidents (N_{nuag}) of more than 32% in 2010 compared to 2002 has been reached. Finally, even if Italy remains the country with the higher level of accidents, it has had the reduction slope (NK_{nuag}) similar to United Kingdom, but it remains quite negative for all investigate period. Similarly, it happens for deaths with the only difference that both Germany and United Kingdom start from a low value of deaths and their trends are quite constant. The Italian decrease rate (2010 vs 2002) is about equal to 80%. This result has been obtained thanks to a reduction of number of deaths (i.e. 30%) and an increasing of vehicle-kilometres of about 26%. It demonstrates that Italy is implementing useful actions (e.g. point driving licences, tutor system for revealing the average speed), but other efforts should be done.

4 The reference scenarios for the accidents involving urban goods vehicles in Europe

4.1 The urban junction as critical situation

The subsequent reported analysis refers to the location of accidents. More than 60% involving goods vehicles happens at *urban junctions* and as argued by Luona and Sivak [24] measures addressed to improve safety in these places can have environmental benefits, contributing hence to improve urban sustainability. The number of deaths (N_{nudg_j}) at these points is averagely comprised between 23% (in Germany) and 46% (in United Kingdom) that seems to be quite constant along the years and for all the three considered countries, while the percentages of injuries ($P_{nudg\_j} = N_{nudg\_j} / N_{nudg}$) are averagely higher than 50% (Table 5).

Then, the analysis on junctions was detailed in order to estimate the average slope of percentage lines. The results show that the average slope of line for accidents occurred at junctions is positive for Italy, while it is negative for the Germany and United Kingdom. The same happens for injuries: the Italian average slope is positive contrarily to what it has been estimated for Germany and United Kingdom. The average number of deaths is going down for all three investigated countries (Table 5).

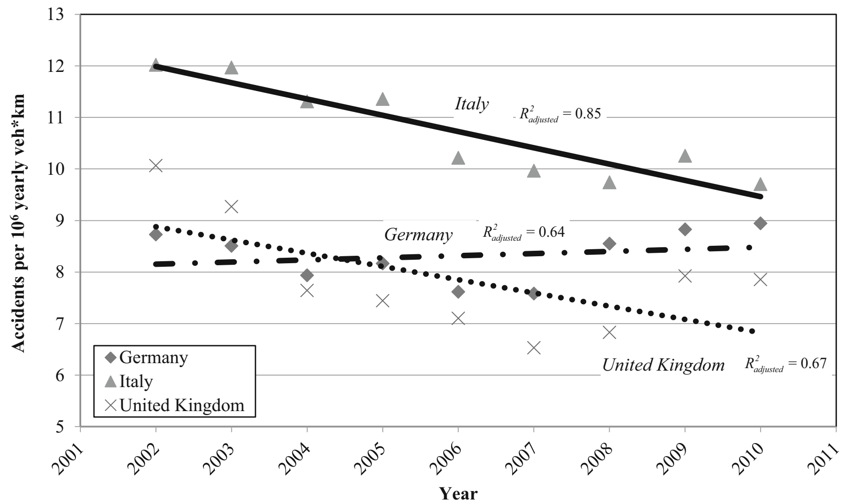
The analyses were hence performed excluding the accidents on urban motorways. The percentages of accidents involving goods vehicles in urban areas (P_{nuag_j}) from 2000 to 2010 are averagely the 68% in the United Kingdom, 59% in Germany and 52% in Italy. The average percentage of deaths (P_{nudg_j}) are respectively 46%, 23% and 34%. Furthermore, in the United Kingdom, these percentages are quite constant along the investigated period for accidents and injuries (P_{nuig_j}, average slope for both equal to −0.1%), while high variation was revealed for deaths (min = 17% and max =67%;

Table 4 National trend factors of number of accidents, deaths and injuries in urban accidents involving goods vehicles (from 2000 to 2010)

	Accident			Death			Injury		
	Average yearly number $N_{nuag} = N_{na} * P_{nua} * P_{nuag}$	Average modelled slope	$R^2_{adjusted}$	Average yearly number $N_{nudg} = N_{nd} * P_{nud} * P_{nudg}$	Average modelled slope	$R^2_{adjusted}$	Average yearly number $N_{nuig} = N_{nai} * P_{nui} * P_{nuig}$	Average modelled slope	$R^2_{adjusted}$
Germany	21,252	-470.54 (−7.1)	0.85	23.4	-0.58 (−1.4)	0.87	4342	-94.67 (−4.8)	0.88
Italy*	16,650	-448.59 (−10.3)	0.93	41.8	-2.82 (−2.5)	0.91	4403	-100.03 (−5.6)	0.84
United Kingdom	15,017	-727.20 (−17.2)	0.97	14.5	-1.57 (−5.1)	0.94	3970	-254.33 (−16.0)	0.97

(−) t-st value; after 2001

Fig. 1 National rate of yearly urban accidents involving goods vehicles per 10^6 veh*km (NK_{nuag})



average slope equal to −0.9%). Germany presents the higher yearly average reductions: 0.3% (accidents), 0.9% (deaths) and 0.5% (injuries). The Italian situation is quite different: the yearly average percentages of accidents and injuries increase respectively of 0.1% and 0.3%, while the deaths reduce of 0.6%. Such analysis showed that only for the United Kingdom different modelled slopes have been revealed considering the presence of urban freeway in the analysis data: higher value for deaths (from −0.6% to −0.9%) and lower value for injuries (from −0.1% to 0.0%).

All the above estimated slopes are quite low with respect to the yearly average values. In fact, according to the estimated trends many years need before to have a reasonable reduction of accidents, deaths and injuries.

Table 5 National trends of ratio between road fatalities at urban junctions and total urban road fatalities (involving goods vehicles in urban areas; P_{nuag_j}; P_{nudg_j}; P_{nuig_j})

	Average	Average modelled slope	R^2_{adjusted}
Germany			
- accidents (P_{nuag_uj})	59%	-0.3% (−4.7)	0.91
- deaths (P_{nuig_uj})	23%	-0.9% (−1.2)	0.84
- injuries (P_{nuig_uj})	55%	-0.5% (−5.7)	0.88
Italy			
- accidents (P_{nuag_j})	52%	0.1% (0.7)	0.64
- deaths (P_{nuig_j})	34%	-0.6% (−0.6)	0.63
- injuries (P_{nuig_j})	51%	0.3% (1.6)	0.72
United Kingdom			
- accidents (P_{nuag_j})	68%	-0.1% (−1.8)	0.88
- deaths (P_{nuig_j})	46%	-0.6% (−0.5)	0.73
- injuries (P_{nuig_j})	66%	-0.1% (−0.8)	0.71

(−) t-st value

4.2 The road accidents involving urban goods vehicles and pedestrians

The below analysis was developed in order to estimate the involvement of pedestrians, to point out if further actions should be planned for improving capacity to take users away from goods vehicles. In fact, people in the urban area would like to make on foot, and then to adapt the road system to create a network of safe and attractive routes for them (Basile et al. [25]; Dommes et al. [26]; Saidul Islam et al. [27]).

According to COM [28], about 11,000 people die in road traffic in EU urban areas every year. The majority of fatal or serious road traffic accidents involving vulnerable road users take place inside urban areas. Around two thirds of pedestrian fatalities take place in urban areas and 50% of those died in accidents in urban areas are pedestrians or cyclists. During the last decade, the number of pedestrian deaths decreased by only 39% compared to 49% for car driver ones. Therefore, based on this statement, additional effort needs to enhance urban road safety and protects, in particular, the vulnerable users from death and serious injury (Safenet [29]). Then, below, some details on the three investigated countries are reported and the contribution of goods vehicles is pointed out, being very dangerous the outcomes when pedestrians and goods vehicles are involved in accidents.

The obtained results show that the three investigated countries have different trends. United Kingdom has a decreasing trend for number of accidents involving pedestrians and goods vehicles, number of involved pedestrians and percentages of accidents involving goods vehicles and pedestrians. In Italy, although the low significance of modelled slope (probably due to possible seasonal or irregular movements of time series that the few available data do not allowed to investigate more in-depth), all these statistics remained quite constant along the investigated years, while the United Kingdom has the yearly slope higher than Germany and Italy. Besides, the United Kingdom presents the higher percentage of accidents involving pedestrians, and unfortunately, these percentages have increasing trends for all countries (Table 6). In addition, although other trends are negative, the low values of yearly slope have to be point out, showing that much has to do in order to preserve vulnerable users.

Detailing the above analyses at junctions, it emerges that: the low level refers to Italy and the higher one occurs in United Kingdom (Fig. 2). All investigated countries present rising trends, and this shows the centrality of the problem and more analyses should be carried out in order to implement specific and more performing actions.

According to the high level of attention to road safety, it is hence important to identify how the urban transportation network can most appropriately perform the functions required by the area. Therefore, each road and subsequently each junction in the network need to be examined in terms of their current functions and their observed performances. Much of the focus in traffic engineering is on junctions where congestion occurs, where the number of potential conflicts increases with the possible range of vehicle movements, and hence where vehicle to vehicle road crashes concentrate. Besides, pedestrians are channelled to cross roads at junctions. Following Cantillo et al. [30], Elvik [31] and Agarwal [32], some variables could be hence investigated in order to evaluate the performances of junctions according to the various characteristics of the road layout and traffic control at the pedestrian crossings. This includes the number of directions from which vehicles may approach a pedestrian crossing (*arms*: an indicator of the number of traffic movements that a pedestrian or cyclist must attend to when crossing the road), the number of lanes, the presence of a refuge, the presence of traffic signal control, speed limit and the 85th percentile speed of approaching motor vehicles. Then, a single joint safety index can be obtained combining different junction characteristics related to traffic, design, visibility and accessibility (macro-characteristics, *MC*). For example, a joint index could be defined as follows:

$$JI = \sum_m w_m \cdot \sum_j \left(w_{m,j} \cdot C_j \right)$$

where

- $w_{m,j}$ is the weight of characteristic C_j (e.g. pedestrian-vehicle conflict points) associated to general macro-characteristics *MC* (e.g. design);
- w_m is the weight of general macro-characteristics *MC* contributing to the general safety goal.

An application of such an index is provided by Basile et al. [25], which index was used for evaluating and ranking more than 200 junctions in 17 European cities.

5 Methods to safety assessment of road accidents for planning

Continuous monitoring and effective understanding are required to afford public decision makers the ability to successfully design and implement transport policies while responding adequately to new challenges (Gudmundsson et al. [33]; Ben-Akiva et al. [34]), especially in the freight transport field.

Table 6 Trends of total national road accidents involving urban goods vehicles in the larger European countries (from 2000 to 2010)

	Yearly average	Average modelled slope	$R^2_{adjusted}$
Germany			
Number of accidents with pedestrians involved	1918	-14.4 (−2.1)	0.77
Number of pedestrians involved	2004	-16.25 (−2.2)	0.76
Percentage of accidents with pedestrians involved	9.2%	0.14% (5.0)	0.84
Italy*			
Number of pedestrians involved	1171	-2.5 (−0.5)	0.61
Number of accidents with pedestrians involved	1030	-2.2 (−0.5)	0.22
Percentage of accidents with pedestrians involved	6.7%	0.17% (4.4)	0.81
United Kingdom			
Number of pedestrians involved	1341	-60.6 (−14.6)	0.96
Number of accidents with pedestrians involved	1262	-57.0 (−14.2)	0.96
Percentage of accidents with pedestrians involved	12.2%	0.08% (2.02)	0.81

*(−) t-st value; * = after 2001*

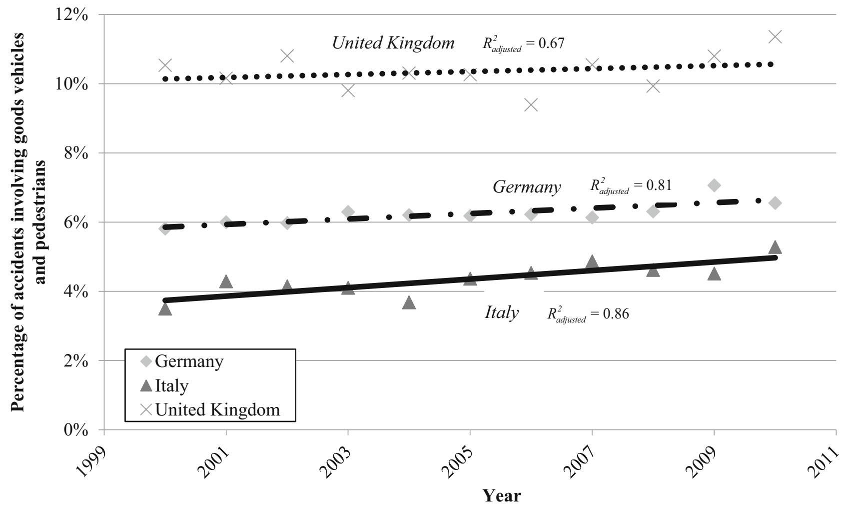


Fig. 2 Trends of total national road accidents involving goods vehicles and pedestrians at urban junctions

The European Commission has promoted the concept of sustainable urban mobility and has supported guidelines for developing Sustainable Urban Mobility Plans (SUMP [7]). To meet the EU goal, the analysis of the mobility situation and the development of future scenarios to be implement has to be supported *ex ante* in a quantitative and qualitative way as summarised below.

According to main data evidenced in the previous sections, urban areas and, in particular, urban goods vehicles have to be point out if the zero-accident EU goal must be pursued. In this context, the study of road accidents requires specific data analysis to obtain the risk factors and the safety performances. Several actors and choice dimensions are involved in this process. Therefore, it is important to have methods and models able to assess the effectiveness of the actions to be implemented. The current models were mainly developed to simulate some aspects of urban freight mobility (Comi et al. [35]), the integration with road safety model according to goods vehicles is quite neglected (Tsai and Su [36]). They are mainly not integrated in a general framework able to forecast many impacts of implementing traffic, transportation and safety measures at an urban scale.

Then, in planning phase, a general assessment framework that integrates *mobility simulation* and *safety simulation* models needs to be used (Fig. 3). The former one allows assessing ex ante road network performances (particularly flow in the junctions, and crossing flows of good vehicles, cars and pedestrians), while the latter provides the identification of potential black-spots (urban places where the frequency of accidents is higher than other). Merging the two results, the study of specific infrastructural points (such as a road, junction, or parking area) where accidents occur can be carried out.

The results ex ante obtained can address iteratively the changes in plan proposal in order to identify better the solutions for reaching the safety goal.

5.1 Mobility simulation models

Simulation models play a key-role to evaluate the performance of road network in terms of specific indications for each class of sustainability. A large literature exists on passenger mobility but fewer studies have been done on goods vehicles mobility, and, in particular, on analyses that link passenger and goods mobility. The literature review (de Jong et al. [37]; Russo [38]; Holguin-Veras et al. [39]; Comi et al. [35]) shows that, in the past, many of the models, used for simulating urban mobility, do not explicitly consider urban freight mobility and many of them were only theoretical. In particular, the urban freight models have been mainly developed, by researchers, to simulate some aspects of the restocking process and do not start from the end consumer (freight is mainly moved in urban area for satisfying the end consumers' requests).

Few recent studies have analysed shopping mobility as a component determinant for goods mobility and considered that changes in shopping attitudes or actions impacting on purchasing behaviour of end consumers (e.g. location of shopping zone, transport mode used for shopping) can also affect restocking mobility (e.g. vehicle used for shop restocking, delivery frequency and shipment size). Hence, it is difficult to consider the link between the old urban models (developed mainly for logistic trips) and end-consumer models (which are those developed for passenger mobility), and to analyse the complexity of urban transport systems with all the components that make up urban mobility.

According to the earlier analysis, the junctions and the involvement of pedestrians have to be pointed out. Then, the outcome to reduce the interferences among the different components of urban mobility (i.e. passenger and goods movements), able to limit the cause of accidents, requires that the measures to be implemented have to be assessed by models (Tavasszy and De Jong [40]; Ben-Akiva et al. [41]). On the

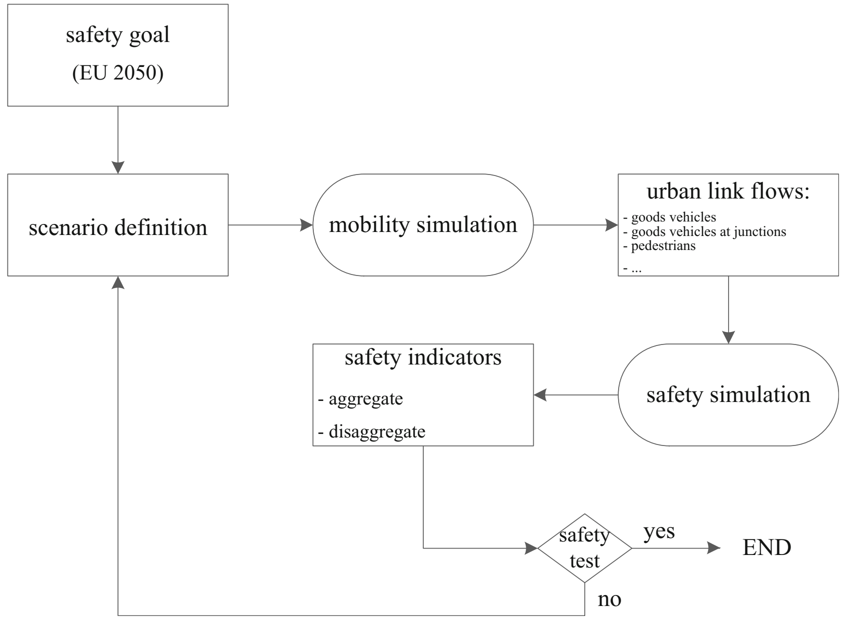


Fig. 3 Framework of the assessment procedure

other hand, in the global urban planning other single urban attractive points have to be studied, such as schools, public offices and so on, to fully reduce the interferences.

The road network should achieve the overall objectives of safety whilst not inhibiting the movement of vehicles and people to any significant extent. Each link (e.g. road) and subsequently each point (e.g. junction) in the network need to be examined in terms of its current function and its observed performance for that role. In this context, the models allow goods vehicle flows on each link (e.g. at each junction branch) to be estimated and accidents, that may result from a combination of factors including conflicting turning movements, speed differentials between motor vehicles and other traffic entities, pedestrians' need to cross roads, to be investigated.

Besides, the above models represent tools that allow to obtain the data required for the disaggregate accident analysis useful for pursuing the safety goals. According to the high level of attention to road safety, there is a range of measures that may be implemented to reduce the number of goods vehicles involved in road accidents and/or their impacts (Elvik et al. [42]). It is hence important to identify how the urban network can most appropriately perform the functions required by the area.

Finally, the model results provide data for improving capacity to take passenger vehicles away from goods vehicles (because they provide paths used by goods vehicles and pedestrians), to calculate quantitative indicators, and to ordinate the road infrastructures in a list to be used by public decision makers as a quantitative and ordinate sequence of intervention priority. For example, the corresponding provision for walking should begin from identifying the pattern of journeys that people in the area would like to make on foot, and then the road system should be adapted to create a network of safe and attractive routes for them.

5.2 Safety simulation models

Traditionally, the safety models focus on data from accidents occurred. This study of road accidents requires specific data analysis in order to obtain the risk factors and the safety performances. Two different methodological analyses can be used (Delfino et al. [43]): *aggregate* or *disaggregate*. Although the disaggregate one could be more performing because of providing detailed indications on single accident scenario, the lack of detailed data, especially when goods vehicles are involved, makes difficult their use and addressed research to investigate more in-depth the aggregate one. Besides, when disaggregate analysis is performed, simulation models play a key-role to evaluate the performance of road network in terms of safety (i.e. number of accidents at nodes and on links) and to calibrate the scenarios from the accidents.

The aggregate analysis should be applied to the accidents that occur in an area where the frequency of accidents is higher than the other ones (i.e. black-spots). The aggregate analysis concerns a large area (such as an urban area or a central business district) and estimates the probability of an accident occurring in relation to a set of attributes that generally are macro. These data are often held by public organizations, can be updated through monitoring surveys, and are used to define and to characterize the phenomenon (e.g. type, temporal trend) as well as to locate the black-spots and to define strategies and measures (Vorko-Jovic et al. [44]). Statistical techniques are commonly used for this type of analysis (Yannis et al. [45]). For example, multiple linear regression, Poisson regression, and negative binomial regression models have been used to identify the relationship among accidents and contributing factors (e.g. data on mobility or on involved users). Besides, due to the increasing potentiality supplied by GIS, some researchers used mapping tools to link road accident with land use factors (Archer [46]; Elvik et al. [42]).

The quantification (in terms of absolute value and frequency) and characterization of accidents are based on available data obtained from Institutional Agencies (e.g. Italian National Institute of Statistics, EuroStat). This type of analysis allows to estimate the number of accidents in an extended area or in relation to particular type of accidents. In the former, the infrastructural black-spots can be identified, while in the latter it is possible to estimate the weight of accident classes in relation to the total number of accidents.

The main outputs of this type of analysis consist in results expressed in terms of absolute or percentage values (PSSU [47]). The absolute values give the dimension of phenomenon, in space and time. These percentages allow us to identify the relevant characteristics of accidents (e.g. number of deaths with respect to the total number of accidents), to verify the incidence of specific factors (e.g. type of involved vehicles). The analysis of these values also provides indications for the existence of black-spots and for comparing different areas (Van Raemdonck and Macharis [48]).

The *disaggregate* analysis concerns an infrastructural element (such as a road, junction, or parking area) and defines common elements in the accidents in order to identify safety measures to avoid impacts in relation to a set of attributes that are generally referred to the single vehicle or element of external environment. Through the disaggregate analysis, the accident scenario can be generated, and different methods have been proposed. According to Delfino et al. [43], they can be classified in collision diagram, cinematic reconstruction and accident scenario.

The collision diagram (Litvin and Datta [49]) is a schematic representation of accidents occurred in a specific place and time. Then, they are drawn with schematic conventional signs (segments, lines, circles). Each conventional sign represents a kind of accident or a kind of collision and each accident is defined with the drawing. All the data relative to the accidents are reported and classified in a table, in order to select the factors that have produced the accidents. This type of method synthetises the major information referring to accident, such as type and severity of accident, date and time, road conditions and so on.

The cinematic reconstruction (Della Valle and Tartaro [50]) of the accident considering as input data the final position of the vehicle after the accident and all the other measured data at the site of the accident. This method allows the accident to be simulated and the effects of the various measures that can be implemented on the accident site to be verified.

Based on the statement that accidents could be aggregated in relation to deeper similitudes, some research linked the accidents within the accident scenario approach (Brenac et al. [51]; Brenac and Megherby [52]). Although the accident scenario approach was proposed some years ago in France, it is still in a research phase. Some developments concern the quantitative formalization of the methodology and its application outside France in order to test the transferability of results and increase the number of available scenarios (Vitetta and Marcianò [53]).

6 Conclusions and operative indications

The paper, within the field of good vehicles mobility, proposed an analysis on accidents occurred in urban areas showing that much has to be done for meeting the zero-accident goal by 2050 in terms of actions and, indirectly, in terms of data collecting (useful for studying phenomenon). Some preliminary conclusions together with operative indications can be synthetized, referring to the paper objectives.

The lack of harmonization of terminology among countries, and even among sectors within them, limits comparability of national data. This problem becomes more relevant when the impact of different types of vehicles are investigated. In fact, few data allow us to explore the impact of goods vehicles in urban areas where more than 50% of worldwide population lives, up to 80% in Europe.

According to the actions that should be implemented to meet the zero-accident goal, the analysis showed that significant results have been obtained on extra-urban roads, but within the cities, the reduction trends are quite flatten, with some warnings. The study showed that differences exist among countries and among some factors (i.e. number of accidents, deaths and injuries). There are countries where the majority of accidents happen in urban area (e.g. the 78% in Italy) and countries where the percentages of urban accidents with respect to the extra-urban are growing (e.g. +0.5% per year in Germany).

Considering urban goods vehicle accidents, important finding concerns of junctions and pedestrians. More than 50% of urban accidents happen at junctions with a significant involvement of pedestrians.

Urban policy-makers when designing urban measures have to deal with a large number of trucks and vans delivering goods in the urban area whilst preserving the economic viability of city businesses and ensuring social sustainability.

The above findings represent the base for developing successful city plans whose ex-ante assessment has to start from the results of freight and passenger simulation models, in terms of vehicle and pedestrian flows. In this respect, the models for city mobility simulation have been recalled showing that a maturity has been reached by literature in this field.

In conclusion, the importance to point out goods vehicles in analysing urban accidents has been detailed and the lines for future development of researches can be identified. The research should be addressed to improve the results discussed in this paper through the development of advanced statistical methods in order to point out in the available time series the seasonal or irregular movements, to develop general city plan procedures that take into account, among the other, also the contribution of goods vehicles to safety because they need for moving goods required by city users.

Finally, the paper would like to stress the new roles played by the road network flows, obtained by mobility models, if they are linked with the safety models. This seems one of the main challenge for the researchers in the next future. Such models could allow to: estimate the commercial vehicle flows at each road infrastructure; estimate a proxy variable of pedestrian flow in each intersection; merge calculated flows with the infrastructural characteristics of the road network; calculate the safety risk; and hence ordinate the urban infrastructures in a list of decreasing risk in order to give to the decision maker a quantitative and ordinate priority of interventions.

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